

REMARKS

Upon entry of the present amendment, claims 1-3, 6, 10, 14 and 16-22 are in the application, of which claims 1, 6, and 17 are independent. New claims 21-22 have been added by the present amendment.

Amendments Presented

New claims 21-22 define aspects of the shot peening steps according to the invention. Applicant respectfully submits that the added claims are fully supported by the original disclosure, including paragraphs [0047] and [0052] defining an exemplary embodiment of the invention. Applicant also respectfully submits that no new matter is introduced by the present amendment.

Response to Office Action

The above-identified Office Action has been reviewed, the references carefully considered, and the Examiner's comments carefully weighed. In view thereof, the present Amendment-D is submitted. It is contended that by the present amendment, all bases of rejection set forth in the Office Action have been traversed and overcome. Accordingly, reconsideration and withdrawal of the rejection is respectfully requested.

Claim Rejections – 35 USC § 103

1. At item 3 of the Office Action the Examiner has rejected claims 1-3, 6 and 10 under 35 USC 103(a) as being unpatentable over JP 2002-060845 (JP '845) for the same reasons as set forth in the prior Office Action.

2. At item 3 of the Office Action the Examiner has rejected claims 17-19 under 35 USC 103(a) as being unpatentable over JP 2002-060845 as applied against claim 1 and further in view of JP 10-204610 (JP '610) for the same reasons as set forth in the prior Office Action.
3. At item 5 of the Office Action the Examiner has rejected claim 14 under 35 USC 103(a) as being unpatentable over JP 2002-060845 as applied against claim 1 and further in view of Nakagawa et al. (US 6,546,968) for the same reasons as set forth in the prior Office Action.
4. At item 6 of the Office Action the Examiner has rejected claims 16 and 20 under 35 USC 103(a) as being unpatentable over JP 2002-060845 as applied against claim 1 and further in view of JP 10-204610 and Nakagawa et al. (US 6,546,968) for the same reasons as set forth in the prior Office Action.

Additionally, at item 7 of the Office Action the Examiner provides the following rebuttal responses to arguments presented in Amendment-C:

- a) In response to applicant's argument that JP '845 and JP '610 are related to different method/apparatus which achieve different results (cast products v. forged products) such that a person of ordinary skill in the art would not consider it obvious to combine teachings thereof in the manner proposed by the Examiner, the Examiner alleges that "... it is common knowledge that forged die and casting die have seizure problem if not properly addressed. The coating and lubricating are typical process to prevent the seizure in the die. Thus, it would be obvious to adapt the concept of solving the seizure problem for the forging die of JP '610 in the casting die of JP '845 to prolong the service life thereof."
- b) In response to applicant's argument that JP '610 is related to a forging die having thermal insulation properties, whereas the instant claimed casting die requires

thermal shock resistance properties to minimize heat cracking and the chipping of the casting die, the Examiner comments that "... the sulphuritriding treatment is applied to the die of JP '610 and that of instant invention. Thus, it is expected that the thermal properties of the casting die of JP '845 having the sulphuritriding treatment of JP '610 will be similar to that of instant casting die."

- c) In response to applicant's argument that the compressive residual stress of cavity surface larger than 1200 MPa, maximum height of roughness of cavity not more than 8µm, a nitrided layer, etc. are required to obtain desired thermal shock resistance properties, whereas the prior art fails to disclose such combination of features, the Examiner alleges that "... JP '845 shows to maintain the compressive residual stress of a die cavity surface having nitrided layer for ... 1000-1300 MPa Further, since it is desirable to maintain the die cavity surface as smooth as possible such that to increase the heat transfer rate between the cast metal and the die surface and also to obtain a better surface quality for the cast article, it would have been obvious to obtain the optimal surface roughness of the casting die through routine experimentation."

Applicant's Response:

Upon careful consideration applicant traverses the Examiner's rejections of the present claims, and submits that each of the present claims is patentably distinct over the applied references whether considered singly or in combination, based on the following.

1. Applicant respectfully traverses the rejection 1) above because the Examiner continues to reject independent claims 1 and 6 based solely on JP '845 even though these claims were

amended in the Amendment-C to recite that the nitrided layer is a compound diffusion layer containing both iron sulfide and iron nitride or that a sulphonitriding treatment is applied to surface of the casting die. JP '845 does not discuss sulphonitriding as conceded by the Examiner in an earlier Office Action. Previously, the Examiner relied on JP '610 in combination with JP '845 for rejecting this feature.

2. Applicant further respectfully traverses the rejections 1) and 2) above, and submits that claims 1-3, 6, 10 and 17-19 are patentable over JP '845 and JP '610, whether considered singly or in combination, for at least the following additional reasons.

A. Applicant respectfully submits that the proposed modification of JP '845 to include a select feature of JP '610 (a sulphonitriding treatment) is improper because such modification is based entirely on a suggestion coming entirely from the Examiner (guided by impermissible hindsight of the applicant's disclosure), rather than on any teaching, suggestion or motivation from the references themselves or from any other evidence of record. In this regard, applicant again notes that persons skilled in the art understand that a forging die requires thermal insulating properties, whereas a casting die does not. As such, persons of ordinary skill in the art would not consider it obvious to apply the sulphonitriding treatment of the JP' 610 forging die to the casting die of JP '845 as proposed by the Examiner, because the references provide no motivation for doing so.

In this regard, applicant notes the Examiner's rebuttal comment a) above, in which the Examiner asserts that "... it is common knowledge that forged die and casting die have seizure problem if not properly addressed", as showing motivation for the proposed combination of reference teachings under 35 USC 103. Applicant respectfully traverses the Examiner's

assertion because it is *not supported by any evidence of record and is not a proper (factual) basis for rejection under 35 USC 103.*

The Examiner appears to be taking judicial / official notice that the alleged fact is common knowledge and commonly accepted as true by persons skilled in the art. Contrary to the Examiner's assertion, applicant respectfully submits that persons skilled in the art understand that casting and forging dies do not, in fact, have similar seizure problems. As previously explained by applicant JP '610 discloses a forging die, it is a well recognized problem of forging dies that forged parts are subject to seizure in the die, whereby it is also well recognized that forging dies require thermal insulation properties therein to properly function. Quite differently, JP '845 relates to a casting die which receives a molten metal that is cooled and solidified to form a cast part, and JP '845 does not disclose lubrication at all. Thus, even if JP '610 would disclose effects of sulphonitriding treatment on thermal insulation properties, an application of sulphonitriding to a casting die which does not require thermal insulation properties (as in JP '845) is never suggested by the references and would not be a matter of common knowledge.

In this regard, the courts have long held that a conclusion that claimed subject matter is *prima facie* obvious must be supported by evidence, as shown by some objective teaching in the prior art or by knowledge generally available to one of ordinary skill in the art that would have led that individual to combine the relevant teachings of the references to arrive at the claimed invention. *See In re Fine*, 837 F.2d 1071, 1074, 5 USPQ2d 1596, 1598 (Fed. Cir. 1988). Rejections based on § 103 must rest on a factual basis, with these facts being interpreted without hindsight reconstruction of the invention from the prior art. The examiner may not, because of doubt that the invention is patentable, resort to speculation, unfounded assumption or hindsight

reconstruction to supply deficiencies in the factual basis for the rejection. See *In re Warner*, 379 F.2d 1011, 1017, 154 USPQ 173, 177 (CCPA 1967), **cert. denied**, 389 U.S. 1057 (1968).

Applicant respectfully submits that the Examiner's assertion above is a type of unfounded assumption or hindsight reconstruction which the courts have warned against.

Further, regarding the Examiner's rebuttal comment b) above, applicant respectfully submits that such comment is quite circular and does not prove/establish anything. Essentially the Examiner is asserting that if he modifies JP '845 to include a sulphonitriding treatment as claimed in the present application the resulting die will have the same properties as the claimed invention. Although the Examiner's assertion may be accurate, it avoids the real issue, i.e., that the references provide do not provide any necessary motivation as required under 35 USC 103 for hypothetically modifying the casting die of JP '845 to include the various features of the claimed invention.

B. Neither of the applied references teach or suggest a casting die having a surface roughness of $\leq 8\mu\text{m}$ as claimed, nor is such feature obvious in view of any teachings of the evidence of record.

In this regard, applicant respectfully submits that the Examiner's rebuttal comment c) above is (again) *not supported by any evidence of record and is not a proper (factual) basis for rejection under 35 USC 103* because it is not common knowledge and is not commonly accepted as true by persons skilled in the art that the die cavity surface shall be maintained as smooth as possible to increase a heat transfer rate between the cast metal and the die surface and also to obtain a better surface quality for the cast article.

In fact, it is not true or a matter of common knowledge that it is desirable to maintain the surface of a casting die as smooth as possible, whereas a surface roughness which is significantly larger than $8\mu\text{m}$ has a conventionally recognized benefit in relation to a casting die such as disclosed in JP '845. For a casting die, a surface roughness (maximum height) of approximately $50\mu\text{m}$ is enough to "obtain a better surface quality for the cast article". In other words, if those of ordinary skill in the art intended to maintain a casting die surface as smooth as possible only in view of "improving a surface quality for the cast article", then such persons would try to make the surface roughness approximately $50\mu\text{m}$, and not to try any obtain a surface roughness of a smaller value.

Further, in a casting die, a molten metal flowing into the die has an oxide coating on its surface, and when the die has a surface roughness of approximately $50\mu\text{m}$, the oxide coating will be caught and broken by the die surface, so that a clean molten metal will flow in the die improving the heat conduction speed between the molten metal and the die. Persons skilled in the art would understand the foregoing, and would also understand that when the surface roughness is not more than $8\mu\text{m}$, the oxide coating of the molten metal will not be caught and broken by the die surface, and the heat conduction might slightly become worse compared to a casting die with a normal surface roughness of approximately $50\mu\text{m}$.

On the other hand, applicant respectfully traverses the Examiner's allegation that the claimed surface roughness is an *obvious matter of optimization through routine experimentation* is unfounded because *none of the applied references ever indicates that surface roughness is a result oriented variable which should be optimized*. Rather, the present disclosure sets this

characteristic as a result oriented variable, and the Examiner is using impermissible hindsight of the present disclosure in formulating his rejection.

Summary of Applicant's Position Regarding the Independent Claims

In view of the foregoing, applicant respectfully submits that in conventional practices of "smoothing of a casting die", it has never been an object / consideration such that both a nitrogen atom and a sulfur atom are bonded to Fe with ease to form a nitrided layer containing iron sulfide. Correspondingly, an appropriate range of a surface roughness of a casting die to achieve the above object has not been heretofore known, and none of the references of record suggest aspects of the claimed invention addressing same.

The above object is not in any way addressed by JP '845, whereas the Examiner has conceded that the reference mentions nothing about surface roughness. Accordingly, the Examiner's allegation "smoothing to obtain a better surface quality for the cast article" does not address/encompass the following object of the present invention : to bond both of a nitrogen atom and a sulfur atom to Fe with ease to form a nitrided layer containing iron sulfide. Additionally, in any kind of smoothing based on conventional knowledge / practice, a surface roughness (maximum height) of a casting die surface is not less than 8 μm . Thus, smoothing according to conventional practice does not involve / teach a numerical range of the maximum height, which is an indispensable feature for the present invention, such that it would never be obvious to try and determine an optimum surface roughness based on the applied references which do not identify surface roughness as a result oriented variable.

Further, although JP '845 discloses a process in which a new casting die is treated in peening and nitriding steps similar to the steps applied to a used casting die according to the

present invention, e.g., a (first) shot peening treatment is carried out, followed by a nitriding treatment, and a (second) shot peening treatment, such treatment steps in JP '845 do not necessarily mean that a maximum surface roughness of less than 8 μm will be achieved. For example, if projection pressure or shot speed is changed the surface roughness is also changed after the process. See for example, Fig. 3 of JP 2001-009725 (copy enclosed herewith). In some situations, the maximum height (R_y) may exceed 8 μm (after two shot peening treatments) and 16 μm (after one shot peening treatment).

Applicant respectfully submits that the shot peening conditions disclosed in JP '845, including paragraph [0025] thereof, are clearly different than those of the present invention, e.g., such as discussed at paragraphs [0047] and [0052]. Given this fact, as well as the fact that the surface roughness of the die is also changed such that it may exceed 8 μm rather than 16 μm if the projection pressure or shot speed is changed, any maximum height (surface roughness) disclosed in JP '845 is never the same at that of the presently claimed invention since the shot peening conditions are different.

C. Regarding the rejections 3), 4) above, applicant respectfully traverses such rejections for those reasons discussed in relation to the independent claims, and because the proposed further modification to JP '845 relative to a select feature of Nakagawa is based entirely on a suggestion coming from the Examiner (guided by impermissible hindsight of the applicant's disclosure), rather than on any teaching or suggestion of the references themselves.

As previously argued, Nakagawa discloses a bond magnet and a method of manufacturing same, e.g., molding a mixture of magnetic powder and resin-based binder under controlled conditions to achieve a desired density ..., such that this reference is non-analogous

art to the claimed casting die because the reference does not pertain to the field of the present invention (surface treatment of a casting die) and also does not pertain to the problem addressed by the present invention (the limited service lives of conventional casting dies).

Correspondingly, persons skilled in the art would not have, in the first instance, have looked to Nakagawa even if they were considering the possibility of modifying the casting die of JP '845.

Based of the foregoing, applicant respectfully submits that, the claimed invention includes features which are neither disclosed nor suggested in any of the applied references JP'845, JP'610 and Nakagawa et al., considered either singly or in combination. Further, the claimed invention including these features obtains an excellent effect which cannot be expected from JP'845 and/or JP'610, i.e., significantly prolonged service life of the casting die. Therefore, the present invention is not obvious over the disclosures of JP'610, JP'845 and Nakagawa et al., considered either singly or in combination.

For all of the foregoing reasons, applicant requests reconsideration and withdrawal of the rejection of claims 1-3, 6, 10, 14 and 16-20 under 35 USC §103(a).

Other Matters

Applicant respectfully requests that the Examiner approve the drawings filed in the application, while noting that no box on the Office Action Summary (item 10) has been checked in any of the Office Actions to date.

New claims 21-22 are believed to be allowable over the references of record based on the foregoing arguments concerning the merits of independent claims 6 and 17, and based on the merits of the additional features recited in the new claims.

Applicant respectfully submits that all of the above amendments are fully supported by the original disclosure including the drawings. The applicant also respectfully submits that no

new matter have been added into the application by the present amendments to the claims and specification, since all of the subject matter thereof was expressly or inherently disclosed in the original specification and drawings.

Conclusion

Based on all of the foregoing, applicant respectfully submits that all of the rejections set forth in the Office Action are overcome, and that all of the pending claims are believed to be allowable over all of the references of record, whether considered singly or in any reasonable combination. It is applicant's contention that no possible reading of the references, either singly or in any reasonable combination, can be viewed as teaching applicant's claimed invention. For all of the above mentioned reasons, applicant requests reconsideration and withdrawal of the rejection of record, and allowance of each of the pending claims.

The application is now believed to be in condition for allowance and a notice to this effect is earnestly solicited.

If any issues remain unresolved, applicant respectfully requests that the Examiner telephonically contact applicant's undersigned representative to expedite prosecution of the application.

Favorable consideration is respectfully requested.

Respectfully submitted,



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HIGH-STRENGTH SPRING AND MANUFACTURE OF SAME

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Publication date: 2001-01-16

Inventor: AOKI TOSHINORI; SAKAKIBARA TAKAYUKI; WAKITA MASAMI

Applicant: CHUO HATSUJYO KK

Classification:

- International: B24C1/10; B24C1/10; C21D1/06; C21D7/06; C21D9/02; C22C38/00; C22C38/04; F16F1/06; B24C1/10; B24C1/10; C21D1/06; C21D7/06; C21D9/02; C22C38/06; C22C38/04; F16F1/02; IPC1-7; B24C1/10; B24C1/10; C21D1/06; C21D7/06; C21D9/02; C22C38/00; C22C38/04; F16F1/02

- European:

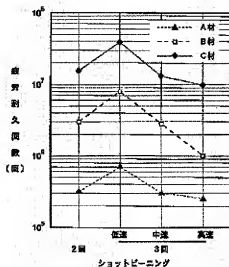
Application number: JP20000127067 20000427

Priority number(s): JP20000127067 20000427; JP19990123113 19990428

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Abstract of JP2001009725

PROBLEM TO BE SOLVED: To provide a spring that is high in strength and in formability at the same time. SOLUTION: This manufacturing method subjects a formed spring to nitriding and to a plurality of cycles of shot peening, the last one of which projects shot balls of a diameter of 0.05 to 0.25 mm and a hardness of 600 to 850 Hv onto the spring at a projection speed of 20 to 60 m/s. The surface roughness remains small, and the point where a maximal compressive residual stress is present is nearer to the surface. This surface hardening treatment permits the use of materials of appreciable formability.



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【特許請求の範囲】

【請求項1】 ばね成形後、窒化処理を施し、複数回のショットピーニングを施す高強度ばねの製造方法であって、最終回のショットピーニングにおいて径0.05～0.25mm、硬さ600～850HVのショット球をばねに投射することを特徴とする高強度ばねの製造方法。

【請求項2】 最終回のショットピーニングにおけるショット球の投射速度を20～60m/sとすることを特徴とする請求項1に記載の高強度ばねの製造方法。

【請求項3】 窒化処理温度を400～550℃とすることを特徴とする請求項2に記載の高強度ばねの製造方法。

【請求項4】 請求項3に記載の方法で製造し、最終回のショットピーニング後の表面硬さを800HV以上、表面圧縮残留応力を1400MPa以上、表面粗さ R_y を15 μm 以下としたことを特徴とする高強度ばね。

【請求項5】 請求項3に記載の方法で製造し、最終回のショットピーニング後の表面硬さを900HV以上、表面圧縮残留応力を1500MPa以上、表面粗さ R_y を15 μm 以下としたことを特徴とする高強度ばね。

【請求項6】 重量比にしてC:0.63～0.68%、Si:1.30～2.20%、Mn:0.60～0.80%、Cr:0.50～0.80%を含有し、残部Fe及び不可避免的不純物から成る鋼を素材とする請求項4又は5に記載の高強度ばね。

【請求項7】 重量比にしてC:0.63～0.68%、Si:1.30～1.60%、Mn:0.60～0.80%、Cr:0.50～0.80%を含有し、残部Fe及び不可避免的不純物から成る鋼を素材とする請求項4又は5に記載の高強度ばね。

【請求項8】 重量比にしてC:0.63～0.68%、Si:1.20～2.20%、Mn:0.50～0.80%、Cr:0.50～0.80%、V:0.10～0.25%を含有し、残部Fe及び不可避免的不純物から成る鋼を素材とする請求項4又は5に記載の高強度ばね。

【請求項9】 重量比にしてC:0.63～0.68%、Si:1.20～1.60%、Mn:0.50～0.80%、Cr:0.50～0.80%、V:0.10～0.25%を含有し、残部Fe及び不可避免的不純物から成る鋼を素材とする請求項4又は5に記載の高強度ばね。

【請求項10】 重量比にしてC:0.70～0.80%、Si:1.30～2.20%、Mn:0.40～0.70%、Cr:0.40～0.70%、を必ず含有するとともに、Mo:0.10～0.25%、V:0.40～0.60%の中の少なくとも1種を含有し、残部Fe及び不可避免的不純物から成る鋼を素材とする請求項4又は5に記載の高強度ばね。

【請求項11】 重量比にしてC:0.70～0.80%、Si:1.30～1.70%、Mn:0.40～0.70%、Cr:0.40～0.70%、を必ず含有するとともに、Mo:0.10～0.25%、V:0.40～0.60%の中の少なくとも1種を含有し、残部Fe及び不可避免的不純物から成る鋼を素材とする請求項4又は5に記載の高強度ばね。

【発明の詳細な説明】

【0001】

【発明の属する技術分野】本発明は、主に自動車用内燃機関のばねとして用いられる、耐久性・耐へたり性及び耐遅れ破壊性に優れた高強度ばね及びその製造方法に関する。

【0002】

【従来の技術】弁ばね用線材として日本工業規格(JIS)には、弁ばね用オイルテンパー線(SMO-V; JIS G3561)、弁ばね用クロムバナジウム鋼オイルテンパー線(SMOCV-V; JIS G3565)、及び、弁ばね用シリクロム鋼オイルテンパー線(SMOSC-V; JIS G3566)が規定されている。従来、この中では耐久性及び耐へたり性に優れたSMOSC-Vが主に利用されてきた。

【0003】自動車の燃費規制、排ガス浄化等の要請に伴い、自動車エンジン用弁ばねに対しては高回転数化や軽量コンパクト化のために、より高強度化が要望されている。また、懸架ばねについても同様に軽量化のために高強度化が要望されている。その方策の一つとして、浸炭窒化鋼オイルテンパー線の開発も行われている(例えば萩原好敏等「ばね論文集」No.35(1990)pp.13～20、安田茂等「ばね論文集」No.42(1997)pp.1～13)。

【0004】

【発明が解決しようとする課題】しかし、ばねの強度を上げるために材料の強度を上げると、ばね成形の際の加工性(成形性)が低下する。

【0005】本発明はこのような課題を解決するために成されたものであり、その目的とするところは、適切な材料とそれに適した加工法との組み合わせにより、強度と成形性のバランスに優れた高強度ばねを提供することにある。

【0006】

【課題を解決するための手段】上記課題を解決するために成された本発明は、ばね成形後、窒化処理を施し、複数回のショットピーニングを施す高強度ばねの製造方法であって、最終回のショットピーニングにおいて径0.05～0.25mm、硬さ600～850HVのショット球をばねに投射することを特徴とするものである。

【0007】ここで、上記最終回のショットピーニングにおけるショット球の投射速度は、20～60m/sとすることが望ましい。

【0008】また、上記窒化処理は、400～550℃で行うことが望ましい。

【0009】以上のような方法で製造したばねは、最終回のショットピーニング後の表面硬さで800Hv以上、表面圧縮残留応力で1400MPa以上、表面粗さRyで15μm以下とすることが望ましい。

【0010】さらに望ましくは、最終回のショットピーニング後の表面硬さで900Hv以上、表面圧縮残留応力で1500MPa以上とする。

【0011】このよなばねの素材としては、以下のような鋼を用いることが望ましい。

【0012】(A鋼)重量比にしてC:0.63~0.68%, Si:1.30~2.20%, Mn:0.60~0.80%, Cr:0.50~0.80%を含有し、残部Fe及び不可避免的不純物から成る鋼。なお、望ましくはSi:1.30~1.60%とする。

【0013】(B鋼)重量比にしてC:0.63~0.68%, Si:1.20~2.20%, Mn:0.50~0.80%, Cr:0.50~0.80%, V:0.10~0.25%を含有し、残部Fe及び不可避免的不純物から成る鋼。なお、望ましくはSi:1.30~1.60%とする。

【0014】(C鋼)重量比にしてC:0.70~0.80%, Si:1.30~2.20%, Mn:0.40~0.70%, Cr:0.40~0.70%, V:0.40~0.60%の中の少なくとも1種を含有し、残部Fe及び不可避免的不純物から成る鋼。なお、望ましくはSi:1.30~1.70%とする。

【0015】

【発明の実施の形態】ショットピーニングは従来より高強度ばねに対して一般的に施されており、それを繰り返すことにより表面の圧縮残留応力が増加することも知られている。しかし、同じ方法によるショットピーニングを単純に繰り返しても、長時間のショットピーニングを行うのと異なることは少なく、表面の圧縮残留応力の上昇は僅かなものでしかない。

【0016】そこで、使用するショット球の径等を変えて、異なる条件で2回のショットピーニングを施すという提案がなされている(特開平10-118930号)。しかし、この提案ではショット球(投射材)の硬さが1200~1600Hvと非常に高い。本発明では、上記の通り表面に窒化処理を施すため、このような硬いショット球を投射するとショット球が壊れて、ばね表面に鋭い切欠を生成してしまう恐れがある。また、特開平9-279229号公報には、微細ショット球を80m/s以上の高速で被投射物(ワーク)に衝突させる方法が開示されている。しかし、このような高速で投射すると、上記同様ショット球が壊れる確率が高く、表面粗さの増大及び圧縮残留応力の減少という問題が考えられる。

【0017】本発明者らは、素材としての成形性を保持しつつ、表面の圧縮残留応力を更に高め、疲労耐久

性を高めるべく数多くの実験を重ねた結果、ばねに成形した後窒化処理を施し、そこに複数回のショットピーニングを施して最終回のショットピーニングを上記のような条件で行うことにより、良好な結果を得ることができた。その基本的な考え方は、素材として成形性を重視した鋼を選択し、窒化処理及び最適な条件でのショットピーニング処理により疲労耐久性、耐ハタリ性等のばねとしての特性の向上を図るというものである。

【0018】本発明における表面強化のメカニズムは、窒化処理したばねに予めショットピーニングを施すことにより表面にほぼ飽和状態の圧縮残留応力を付与しておき、その上に特別に管理された条件でショットピーニングを施すことにより表面の圧縮残留応力を更に高めるとともに、表面粗さを減少させる等の効果も加え、それらの相乗効果により耐久限を高めるというものである。最終回のショットピーニングの条件を上記の通りにした理由は次の通りである。

【0019】まず、ショット球の大きさについては、図1のグラフに示される通り、ショット球の径が小さいほど表面の圧縮残留応力が大きくなることが判明した。表面の圧縮残留応力は、もちろん疲労耐久性の向上に大きく寄与する。そこで本発明では、十分な表面圧縮残留応力が得られるように、ショット径を0.05~0.25mmとした。

【0020】次に、ショット球の硬さについては、図2に示すように、硬さが低すぎても高すぎてもばね表面の圧縮残留応力は低下し、600~850Hvの範囲とした時に、十分な耐久性を確保するのに必要な程度の表面圧縮残留応力が得られることが判明した。

【0021】そして、ショット球の投射速度については、図3に示すように、投射速度が大きくなるにつれて表面粗さが大きくなり、耐久性に悪影響を与える。しかし、投射速度が低すぎても十分なショットピーニング効果(十分な表面圧縮残留応力)を得ることはできない。上記ショット球を用いる場合、20~60m/sが最適な範囲であることが実験で確かめられた。なお、図3における投射速度のスケールは、ショット投射装置の投射圧力から換算により求めたものである。

【0022】ショットピーニングの回数を2回とした場合と3回とした場合の表面の圧縮残留応力の変化、及び、3回目(最終回)のショット球の投射速度(投射圧力)を変化させた場合の表面圧縮残留応力の変化を図4に示す。また、それらの場合の疲労試験の結果を図5に示す。これらの図において、低速は約50m/s、中速は約70m/s、高速は約85m/sのショット投射速度を表す。

【0023】窒化処理を施した表面に複数回のショットピーニングを施し、最終回のショットピーニングを上記のような条件で行って、ばねの表面硬さを800Hv以上(望ましくは900Hv以上)、表面の圧縮残留応力

を1400MPa以上(望ましくは1500MPa以上)、表面粗さRy(最大高さ;JIS-B0601)を15 μ m以下とすることにより、本発明のばねの耐久性・耐へたり性等の性能はより確実に保障されるようになる。

【0024】本発明に係る高強度ばねの素材として用いる鋼は、上記の通り成形性を主に考慮して選択したものである。

【0025】上記A鋼は、従来の弁ばね用シリコンクロム鋼オイルテンパー線(SWOSC-V)よりも炭素量をやや高くし、シリコン量の上限をやや高くしたものであるが、成形性は十分に確保されている。

【0026】上記B鋼は、同じく弁ばね用シリコンクロム鋼オイルテンパー線(SWOSC-V)よりも炭素量をやや高くし、シリコン量の上限をやや高くするとともに、バナジウムを含有させることにより韌性を向上させ、成形性を向上させたものである。

【0027】上記C鋼は、A、B鋼よりも炭素量を更に高くする一方、モリブデン及びバナジウムを含有させることにより韌性を向上させ、成形性を確保したものである。

【0028】窒化処理の温度は、熱処理後のばねの内部硬さに影響を及ぼす。そのため、本発明では上記鋼を素材として用いる場合、内部硬さの低下を防止するために窒化温度を400～550℃とすることが望ましい。

【0029】

【実施例】本発明に基づいて弁ばねを作製し、各種試験を行った。図6に、実験に用いた3種のばね素材(A材、B材、C材)の鋼の化学組成を示す。これらの素材よりオイルテンパー線材を作成し、図7に示す諸元を有する弁ばねを作成した。コイルリング以降の製造工程を図8に示す。

【0030】3回ショットピーニングを施した後(図8の第3SPの後)の各供試材(A材、B材、C材)ばねの表面の硬さ分布を図9に示す。また、C材の表面の圧縮残留応力の分布を図10に示す。なお、比較のために、C材を2回ショットピーニングしたもの(図8参照)の残留応力分布も示す。そして、各供試材の最高硬さと最大圧縮残留応力の値を対比させた結果を図11に示す。図11から明かな通り、供試材はいずれも表面硬さを800HV以上とすることにより、表面の圧縮残留応力が1400MPa以上となっている。

【0031】供試材ばね代表として、C材の耐久試験の結果を図12に示す。3回のショットピーニングを施した供試材は2回だけの場合(比較材)と比較すると、耐久回数(折損までの回数)が約2倍に向上している。また、耐久限度の応力振幅は約22MPa高くなっている。

【0032】次に、3回目のショットピーニングの際のショット投射速度を低速(約50m/s)、中速(約70m/s)、高速(約85m/s)としたときの各供試材の疲労耐久回数を測定した。各供試材について8本の供試ばねで疲労試験を行い、それらの疲労耐久回数を統計処理して、各ショット条件下での各供試材の10%折損確率を求めた。その結果、図13に示す通り、3回目のショットピーニングの際のショット投射速度は低い方が望ましいことが明かとなった。

【図面の簡単な説明】

【図1】 ショット球の径とばね表面の圧縮残留応力との関係のグラフ。

【図2】 ショット球の硬さとばね表面の圧縮残留応力との関係のグラフ。

【図3】 ショット球の投射圧力・速度と表面粗さとの関係のグラフ。

【図4】 ショットピーニング条件(回数、速度)と表面圧縮残留応力との関係のグラフ。

【図5】 ショットピーニング条件(回数、速度)と疲労耐久回数との関係のグラフ。

【図6】 供試材の素材鋼の化学組成。

【図7】 供試材ばねの諸元。

【図8】 供試材ばねのコイルリング以降の製造工程の説明図。

【図9】 各供試材の、表面下の深さと硬さの関係のグラフ。

【図10】 供試材と比較材の、表面下の深さと圧縮残留応力との関係のグラフ。

【図11】 供試材と比較材の、最高表面硬さと最大表面圧縮残留応力との関係のグラフ。

【図12】 供試材ばねと比較材ばねの耐久試験結果のグラフ。

【図13】 各供試材ばねのショットピーニング条件(回数、速度)と耐久試験結果のグラフ。

【図6】

【図7】

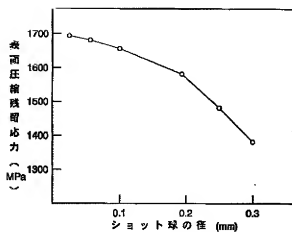
供試材の化学組成 (mass%)

	C	Si	Mn	Cr	V	Mo	Nb
A 材	0.84	2.05	0.71	0.76	0.1	0	0
B 材	0.85	1.40	0.60	0.70	0	0	0
C 材	0.72	1.40	0.80	0.60	0.40	0.15	0

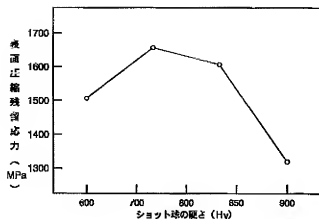
供試材ばね諸元

総径 (mm)	コイル径 (mm)	総巻数	有効巻数	自由長 (mm)	ばね定数 (N/mm)
φ3.4	φ19.2	5.76	4.76	44.6	38.93

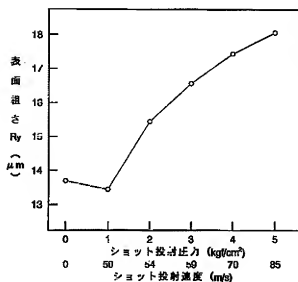
【図1】



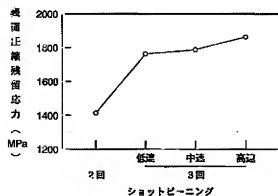
【図2】



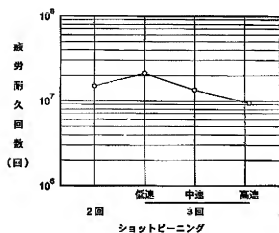
【図3】



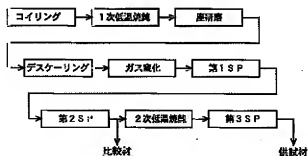
【図4】



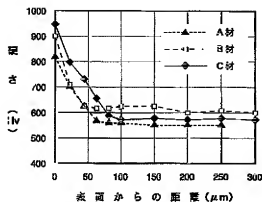
【図5】



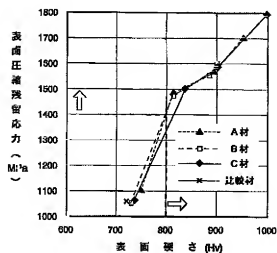
【図8】



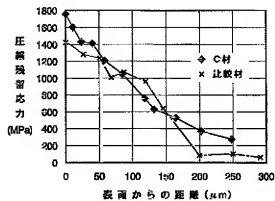
【図9】



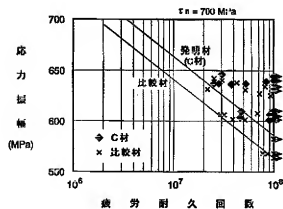
【図11】



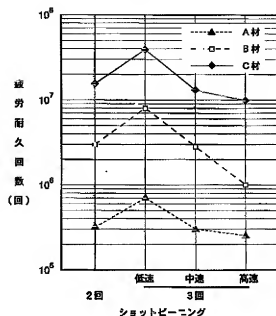
【図10】



【図12】



【図13】



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